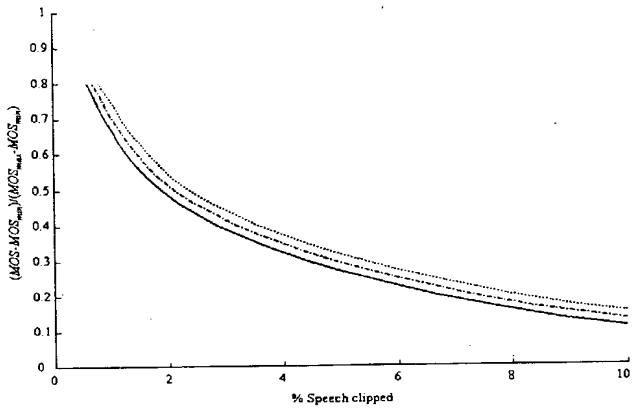
(a)


(MOS-MOS_min)/(MOS_max-MOS_min)
% Speech clipped

(b)

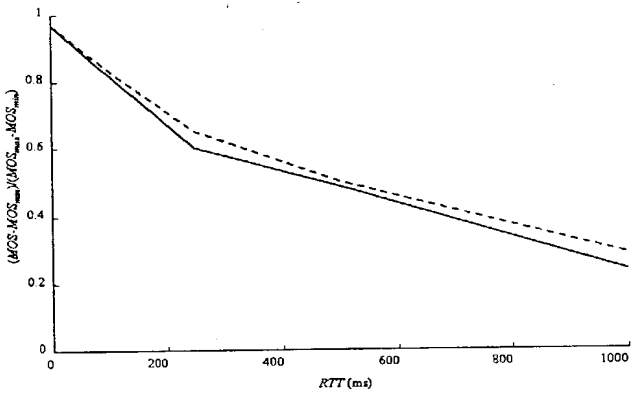
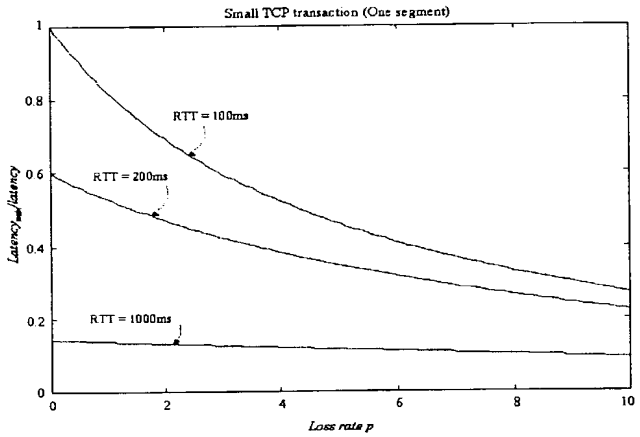

(MOS-MOS_min)/(MOS_max-MOS_min)
RTT (ms)

FIG. 1

(a)


Small TCP transaction (One segment)
RTT = 100ms
RTT = 200ms
RTT = 1000ms
Latency_ideal/latency
Loss rate p
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10

(b)

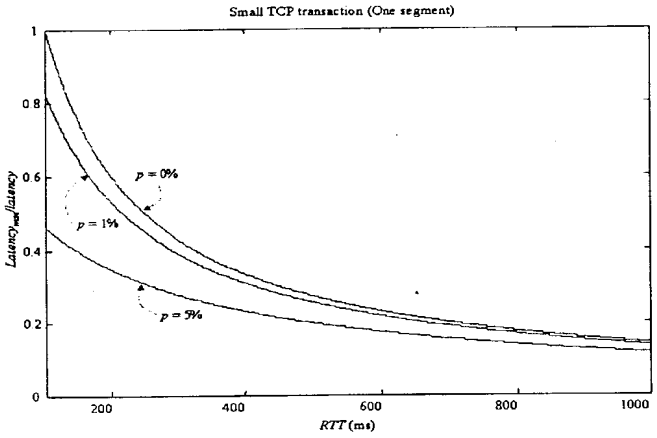
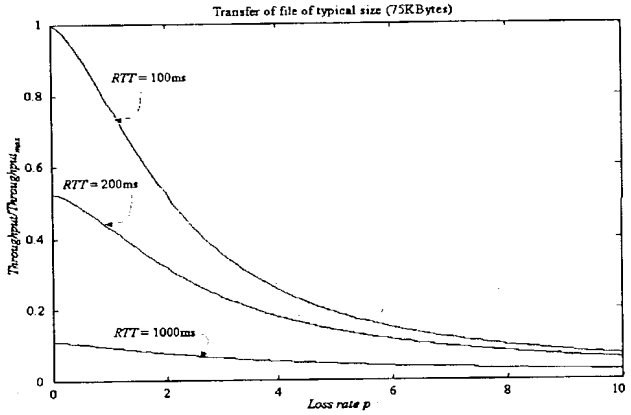

Small TCP transaction (One segment)
p = 0%
p = 1%
p = 5%
Latency_ideal/latency
RTT (ms)
0
0.2
0.4
0.6
0.8
1
200
400
600
800
1000

FIG. 2

(a)


Transfer of file of typical size (75KBytes)
RTT = 100ms
RTT = 200ms
RTT = 1000ms
Throughput/Throughput_max
Loss rate p
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10

(b)

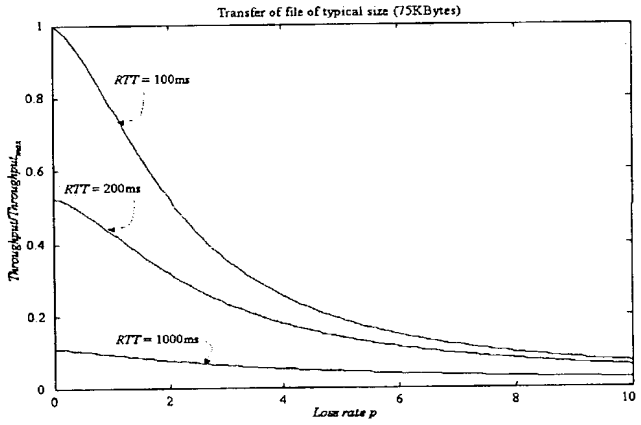

Transfer of file of typical size (75KBytes)
RTT = 100ms
RTT = 200ms
RTT = 1000ms
Throughput/Throughput_max
Loss rate p
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10

FIG. 3

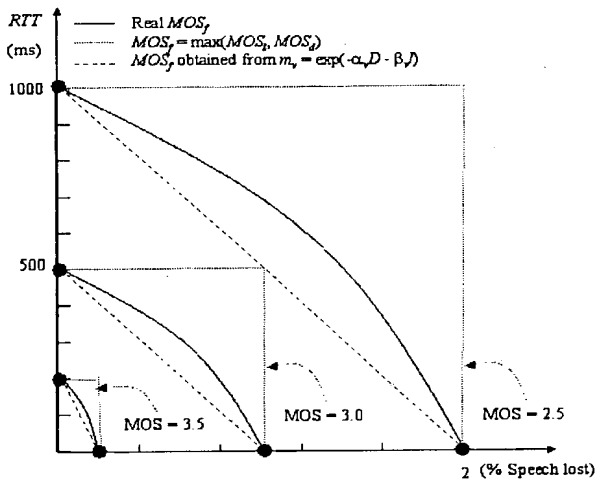
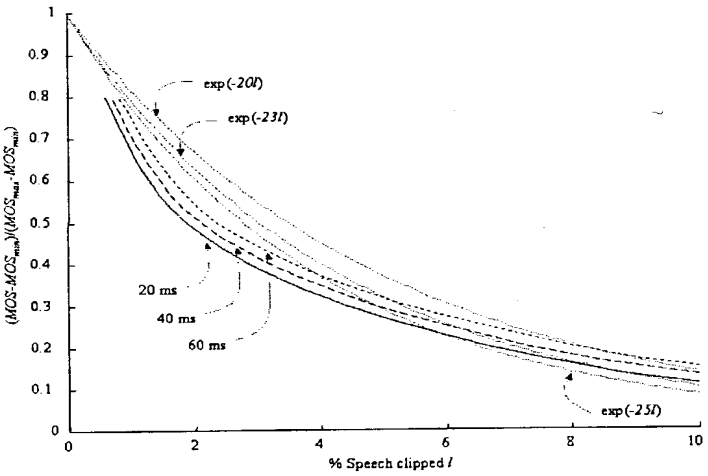

RTT
(ms)
Real MOS_f
$MOS_f = \max(MOS_b, MOS_d)$
MOS_f obtained from $m_f = \exp(-\alpha_f D - \beta_f J)$
1000
500
MOS = 3.5
MOS = 3.0
MOS = 2.5
2 (% Speech lost)

FIG. 4

(a)


exp(-20I)
exp(-23I)
20 ms
40 ms
60 ms
exp(-25I)
(MOS-MOS_min)/(MOS_max-MOS_min)
% Speech clipped I

(b)

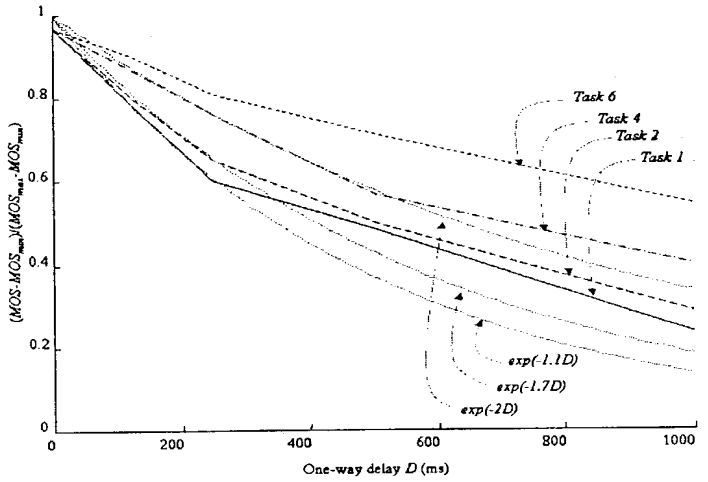
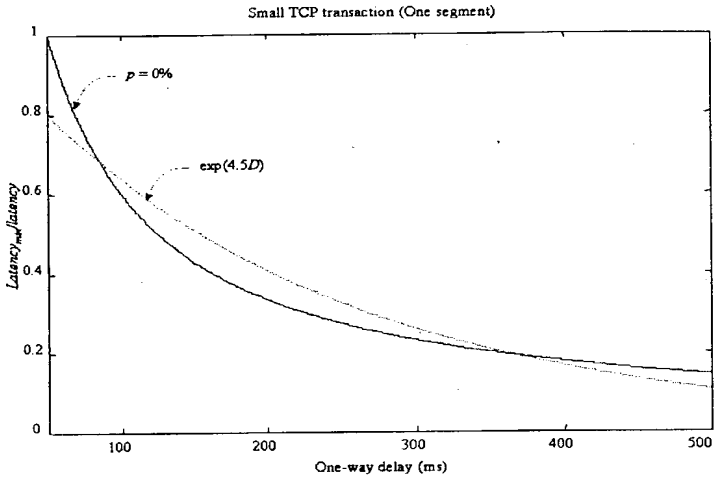

Task 6
Task 4
Task 2
Task 1
exp(-1.1D)
exp(-1.7D)
exp(-2D)
(MOS-MOS_min)/(MOS_max-MOS_min)
One-way delay D (ms)

FIG. 5

(a)


Small TCP transaction (One segment)
p = 0%
exp(4.5D)
Latency_ideal/latency
One-way delay (ms)
0
0.2
0.4
0.6
0.8
1
100
200
300
400
500

(b)

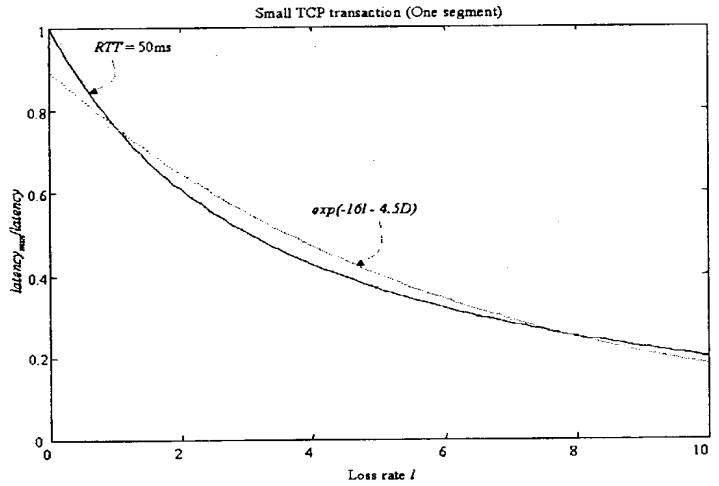
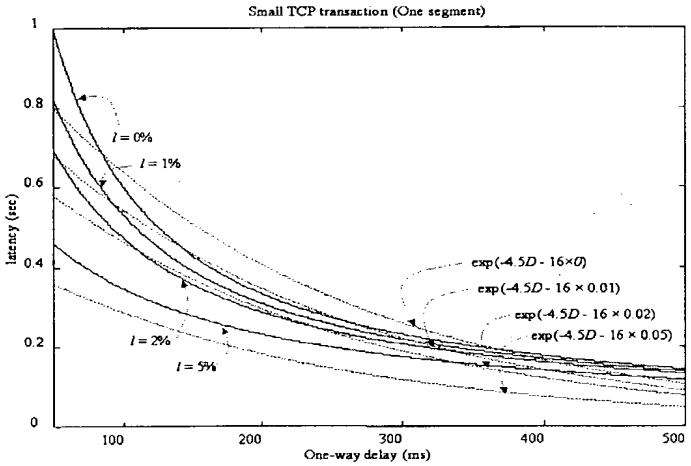

Small TCP transaction (One segment)
RTT = 50ms
exp(-16l - 4.5D)
Latency_ideal/latency
Loss rate l
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10

FIG. 6

(a)


Small TCP transaction (One segment)
latency (sec)
One-way delay (ms)
l = 0%
l = 1%
l = 2%
l = 5%
exp(-4.5D - 16×0)
exp(-4.5D - 16 × 0.01)
exp(-4.5D - 16 × 0.02)
exp(-4.5D - 16 × 0.05)

(b)

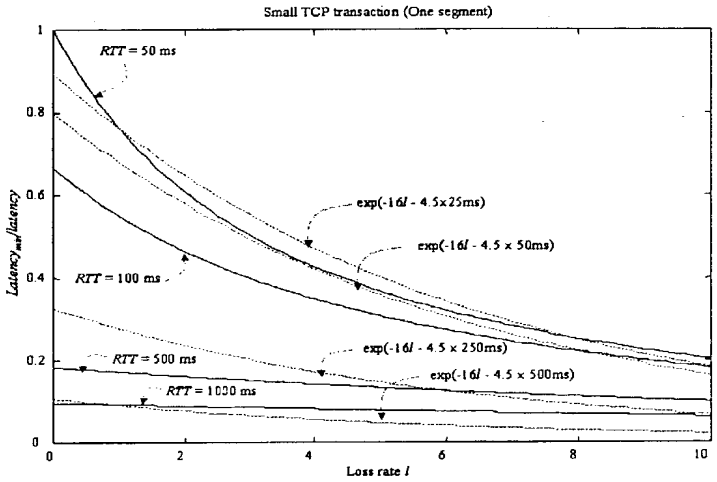
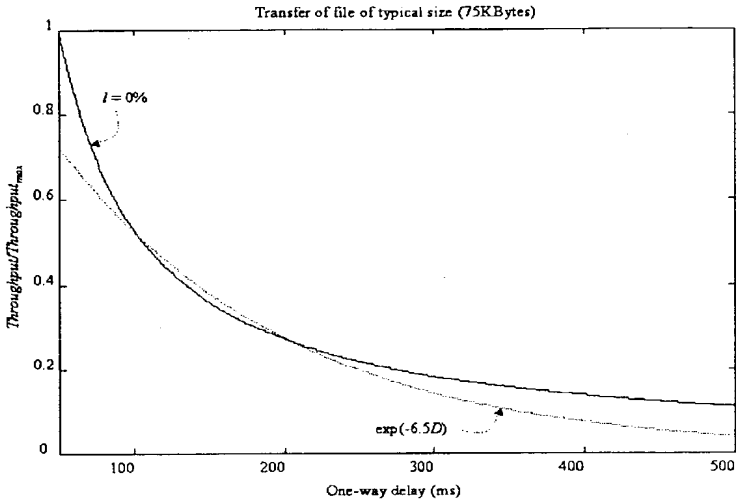

Small TCP transaction (One segment)
Latency_wan/latency
Loss rate l
RTT = 50 ms
RTT = 100 ms
RTT = 500 ms
RTT = 1000 ms
exp(-16l - 4.5x25ms)
exp(-16l - 4.5 x 50ms)
exp(-16l - 4.5 x 250ms)
exp(-16l - 4.5 x 500ms)

FIG. 7

(a)


Transfer of file of typical size (75KBytes)
l = 0%
exp(-6.5D)
Throughput/Throughput_max
One-way delay (ms)
0
0.2
0.4
0.6
0.8
1
100
200
300
400
500

(b)

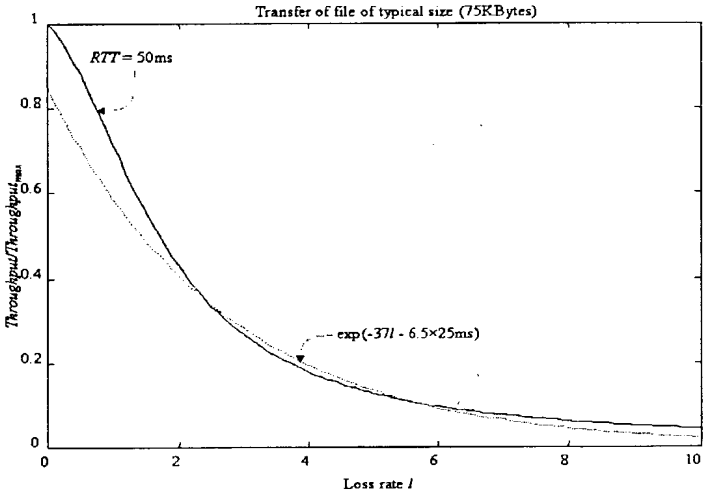
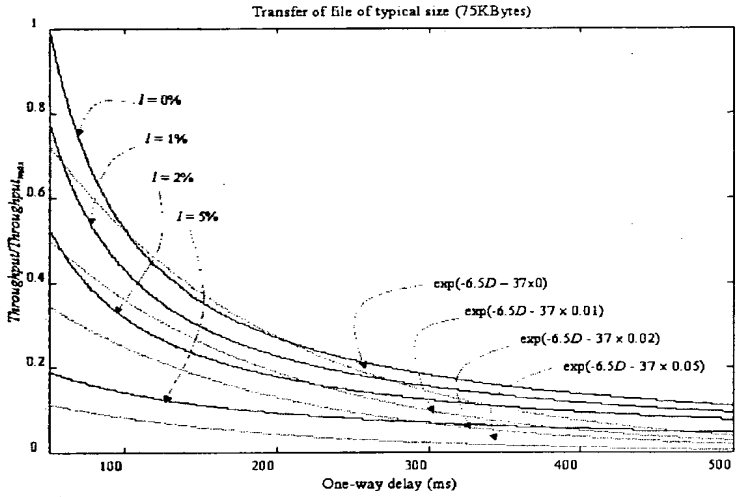

Transfer of file of typical size (75KBytes)
RTT = 50ms
exp(-37l - 6.5×25ms)
Throughput/Throughput_max
Loss rate l
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10

FIG. 8

(a)


Transfer of file of typical size (75KBytes)
Throughput/Throughput_max
One-way delay (ms)
l = 0%
l = 1%
l = 2%
l = 5%
exp(-6.5D – 37x0)
exp(-6.5D - 37 x 0.01)
exp(-6.5D - 37 x 0.02)
exp(-6.5D - 37 x 0.05)

(b)

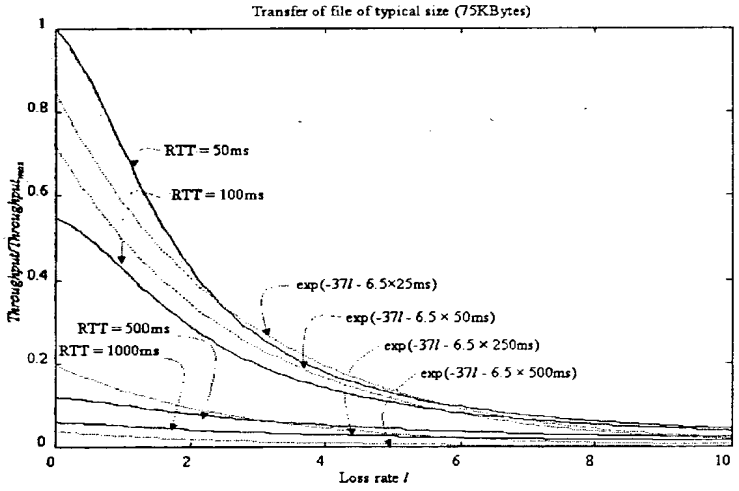

Transfer of file of typical size (75KBytes)
Throughput/Throughput_max
Loss rate l
RTT = 50ms
RTT = 100ms
RTT = 500ms
RTT = 1000ms
exp(-37l - 6.5×25ms)
exp(-37l - 6.5 × 50ms)
exp(-37l - 6.5 × 250ms)
exp(-37l - 6.5 × 500ms)

FIG. 9

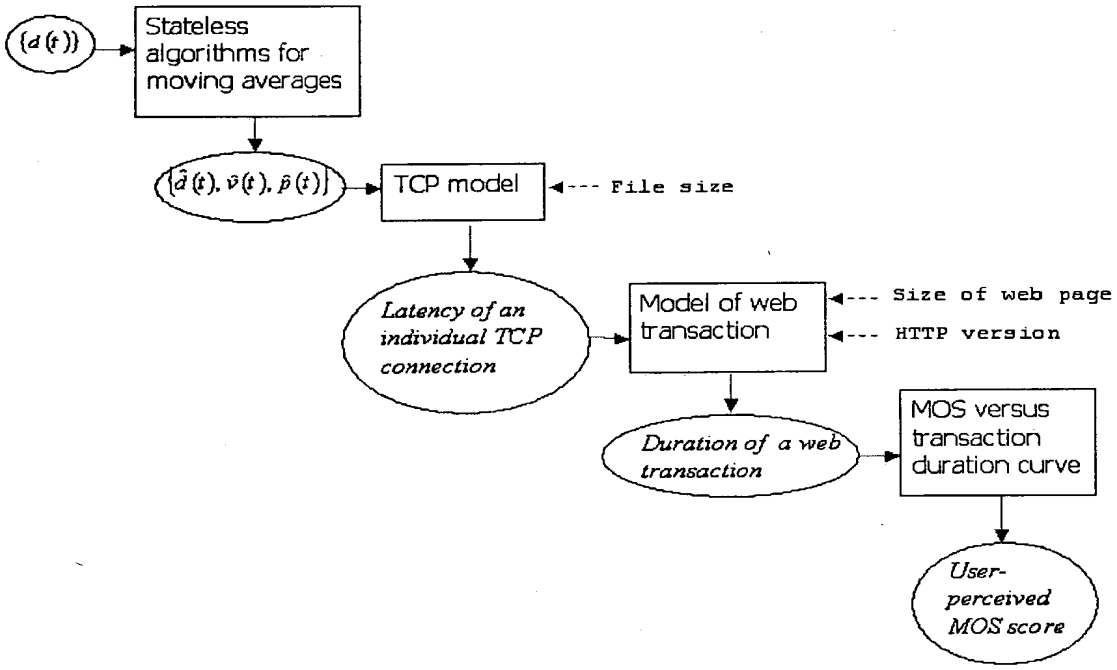

{d(t)}
Stateless algorithms for moving averages
{d̂(t), v̂(t), p̂(t)}
TCP model
--- File size
Latency of an individual TCP connection
Model of web transaction
--- Size of web page
--- HTTP version
Duration of a web transaction
MOS versus transaction duration curve
User-perceived MOS score

FIG. 10

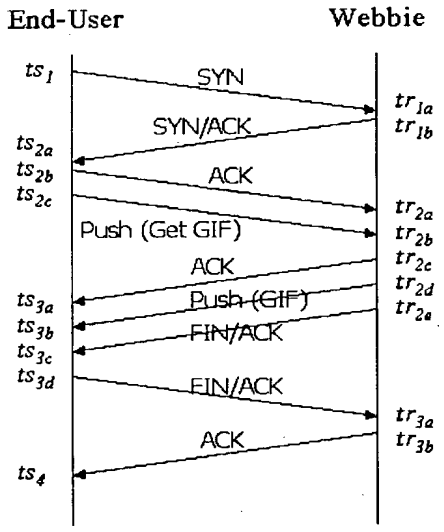

End-User
Webbie
ts_1
SYN
tr_{1a}
tr_{1b}
SYN/ACK
ts_{2a}
ts_{2b}
ACK
ts_{2c}
tr_{2a}
Push (Get GIF)
tr_{2b}
tr_{2c}
ACK
tr_{2d}
ts_{3a}
Push (GIF)
tr_{2e}
ts_{3b}
FIN/ACK
ts_{3c}
ts_{3d}
FIN/ACK
tr_{3a}
tr_{3b}
ACK
ts_4

FIG. 11

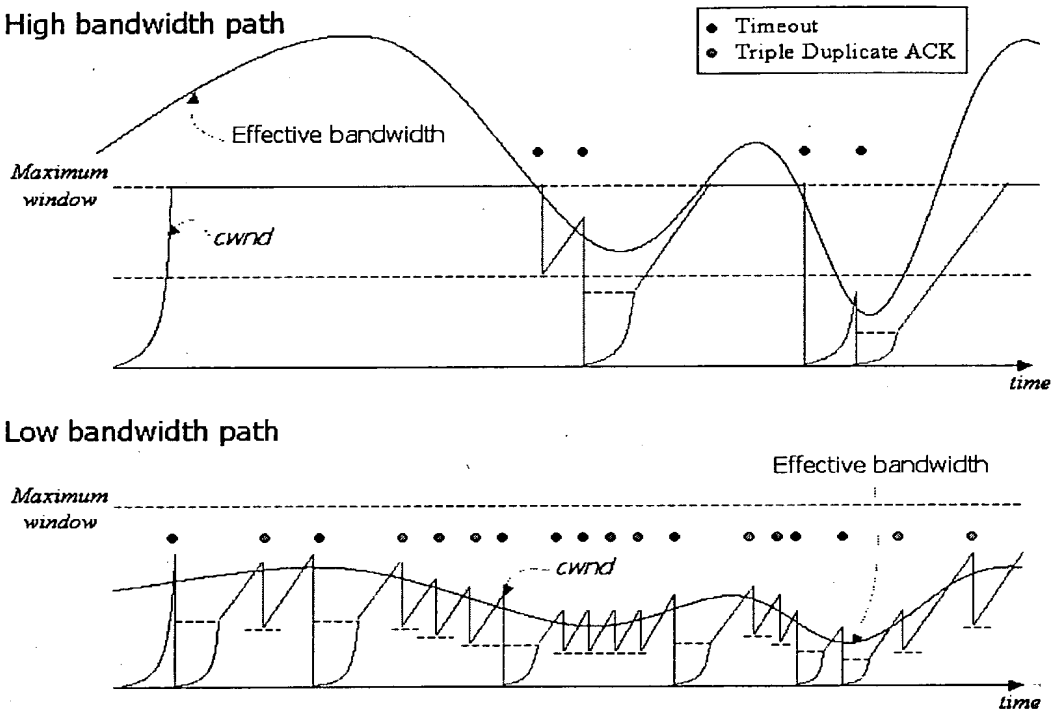

High bandwidth path
Timeout
Triple Duplicate ACK
Effective bandwidth
Maximum window
cwnd
time
Low bandwidth path
Effective bandwidth
Maximum window
cwnd
time

FIG. 12

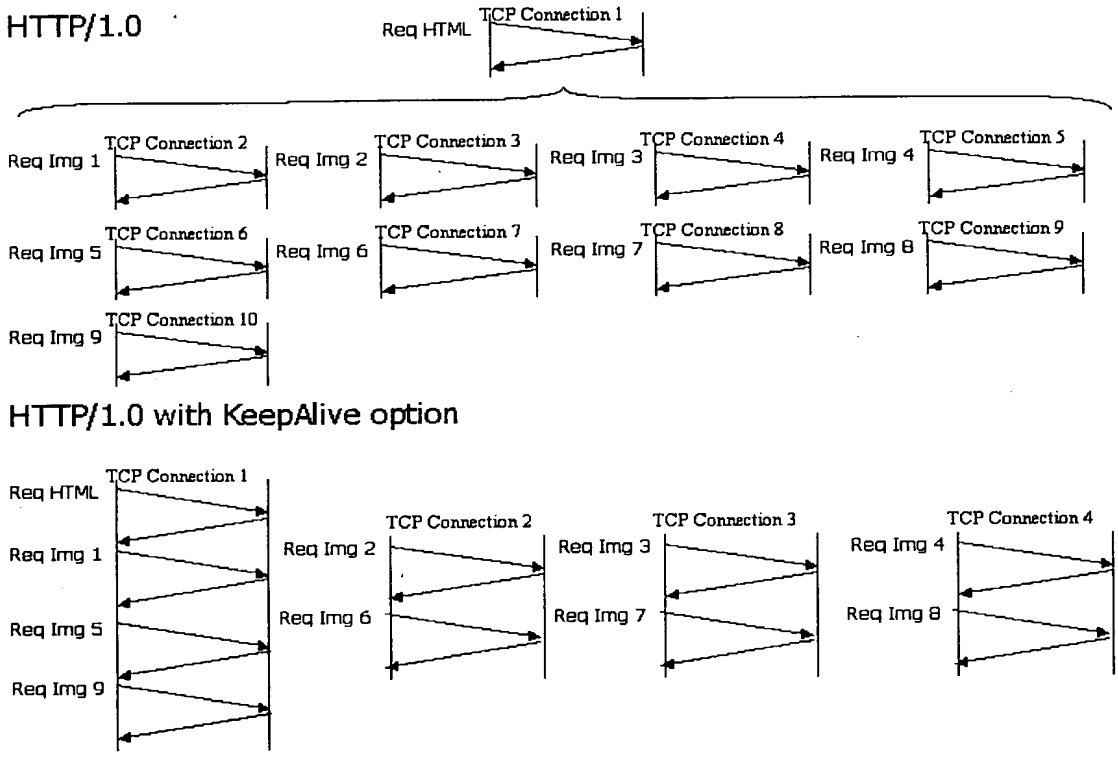
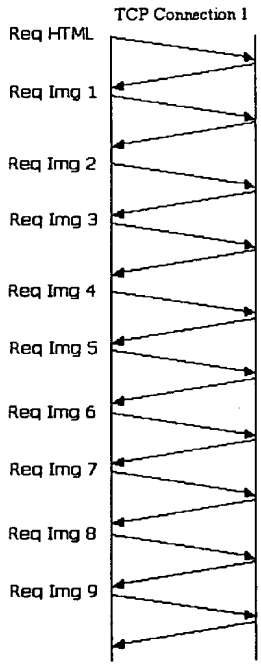

HTTP/1.0
Req HTML
TCP Connection 1
Req Img 1
TCP Connection 2
Req Img 2
TCP Connection 3
Req Img 3
TCP Connection 4
Req Img 4
TCP Connection 5
Req Img 5
TCP Connection 6
Req Img 6
TCP Connection 7
Req Img 7
TCP Connection 8
Req Img 8
TCP Connection 9
Req Img 9
TCP Connection 10
HTTP/1.0 with KeepAlive option
Req HTML
TCP Connection 1
Req Img 1
Req Img 5
Req Img 9
Req Img 2
TCP Connection 2
Req Img 6
Req Img 3
TCP Connection 3
Req Img 7
Req Img 4
TCP Connection 4
Req Img 8

FIG. 13

HTTP/1.1 persistent connection



HTTP/1.1 persistent, pipelined connection

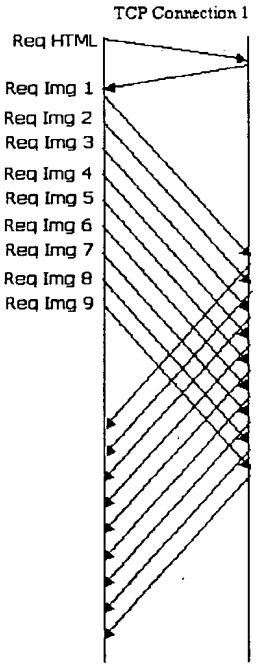
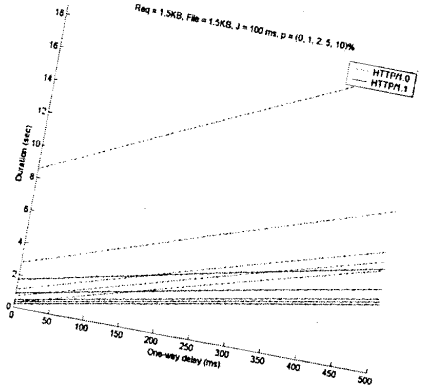


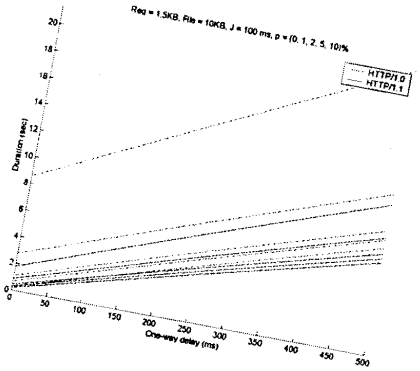
FIG. 14

10/070338

(1)



(2)



(3)

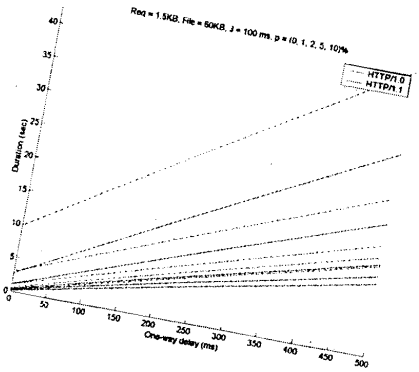
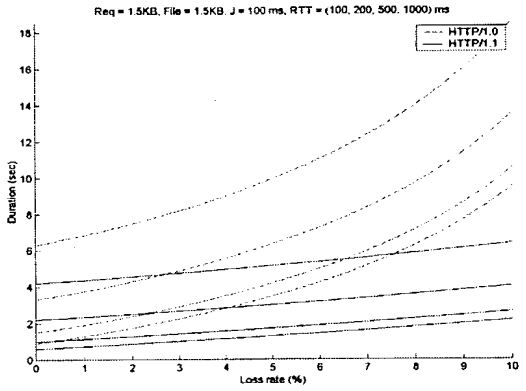
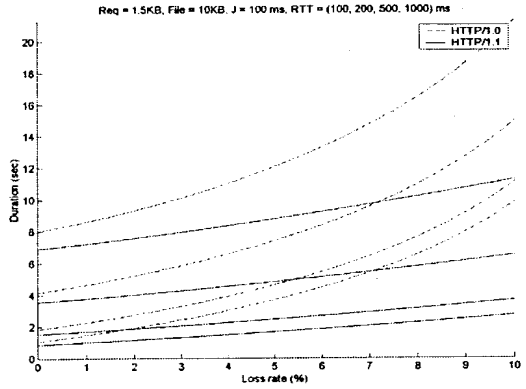


FIG. 15

(1)


Req = 1.5KB, File = 1.5KB, J = 100 ms, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
Duration (sec)
Loss rate (%)

(2)


Req = 1.5KB, File = 10KB, J = 100 ms, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
Duration (sec)
Loss rate (%)

(3)

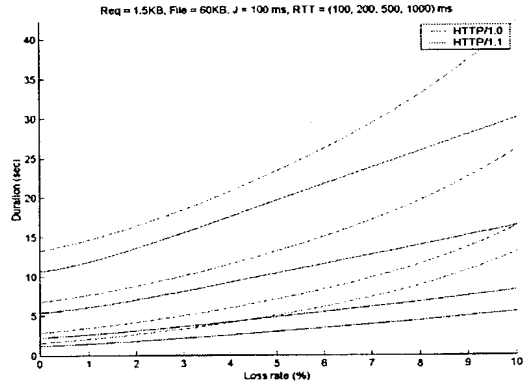
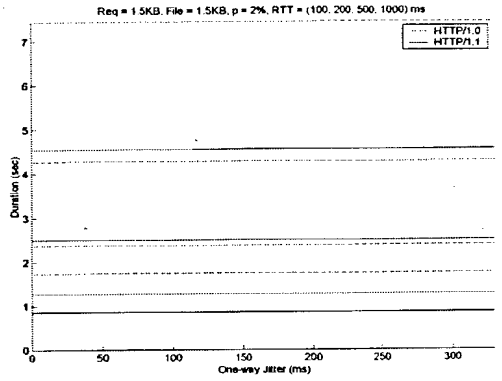
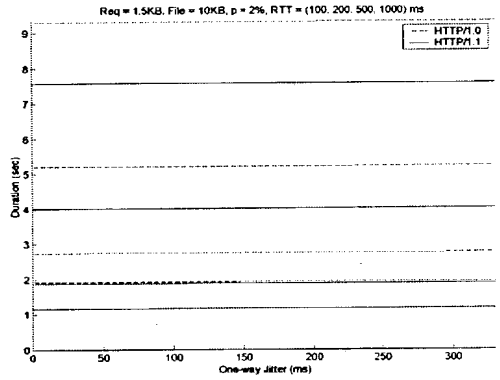

Req = 1.5KB, File = 60KB, J = 100 ms, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
Duration (sec)
Loss rate (%)

FIG. 16

(1)


Req = 1.5KB, File = 1.5KB, p = 2%, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
Duration (sec)
One-way Jitter (ms)

(2)


Req = 1.5KB, File = 10KB, p = 2%, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
Duration (sec)
One-way Jitter (ms)

(3)

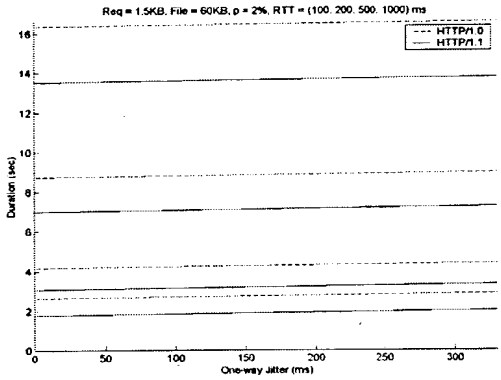

Req = 1.5KB, File = 60KB, p = 2%, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
Duration (sec)
One-way Jitter (ms)

FIG. 17

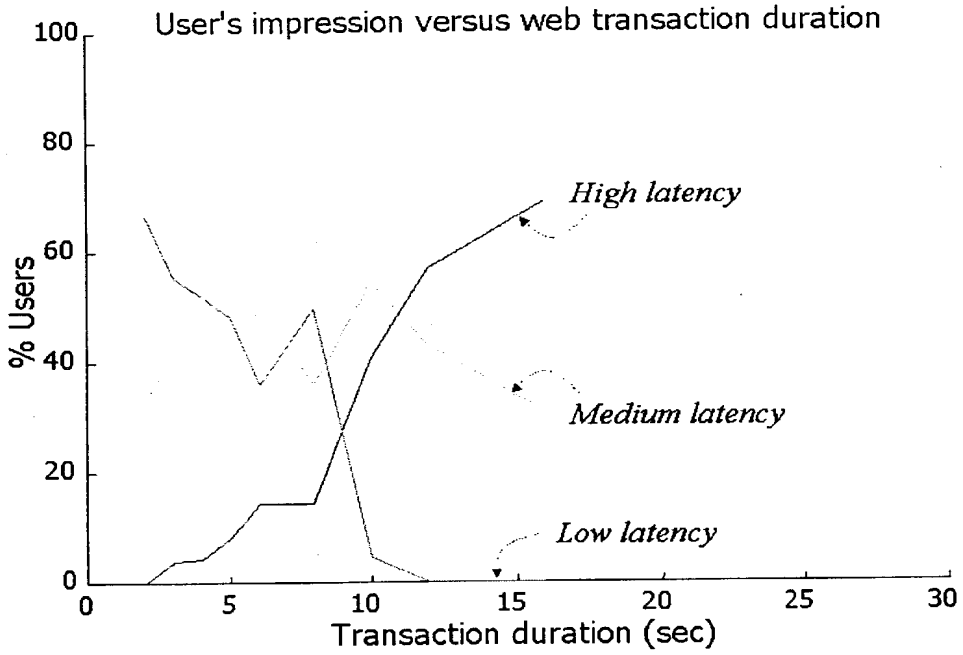

User's impression versus web transaction duration
100
80
60
40
20
0
% Users
0
5
10
15
20
25
30
Transaction duration (sec)
High latency
Medium latency
Low latency

FIG. 18

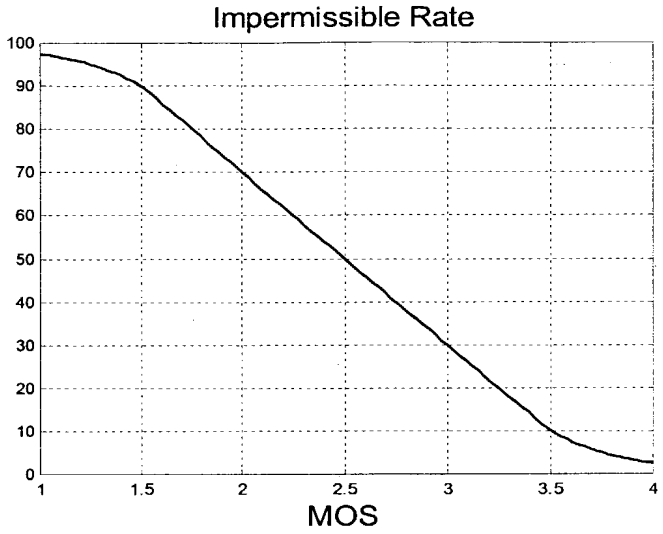
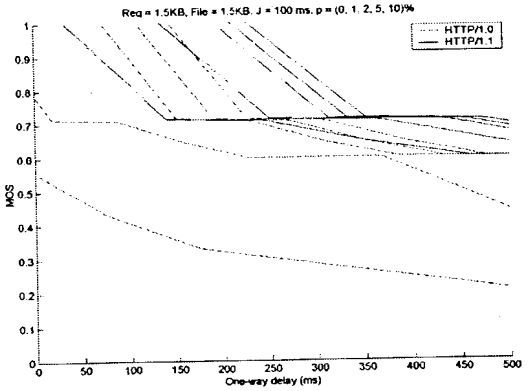
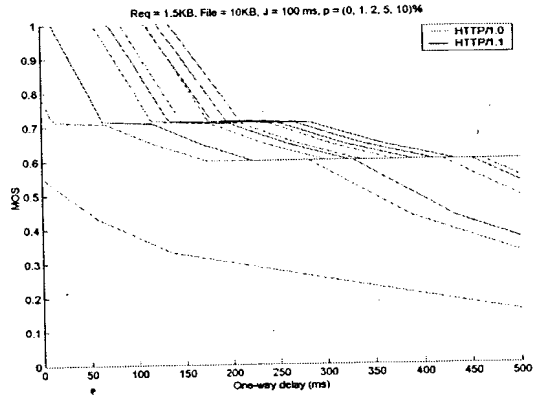

Impermissible Rate
100
90
80
70
60
50
40
30
20
10
0
1
1.5
2
2.5
3
3.5
4
MOS

FIG. 19

(1)


Req = 1.5KB, File = 1.5KB, J = 100 ms, p = (0, 1, 2, 5, 10)%
HTTP/1.0
HTTP/1.1
MOS
One-way delay (ms)

(2)


Req = 1.5KB, File = 10KB, J = 100 ms, p = (0, 1, 2, 5, 10)%
HTTP/1.0
HTTP/1.1
MOS
One-way delay (ms)

(3)

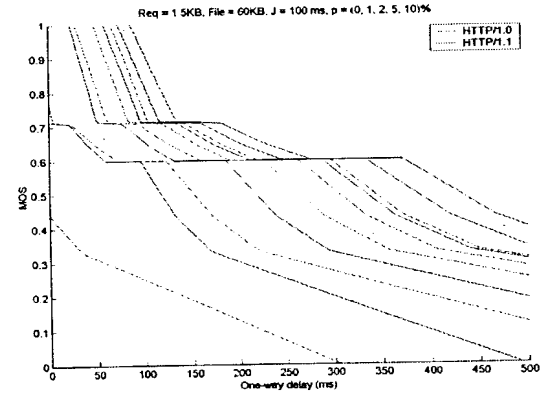
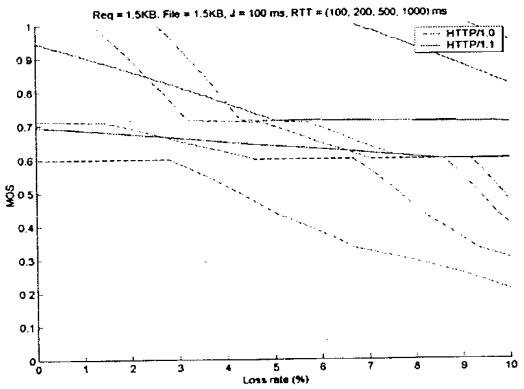
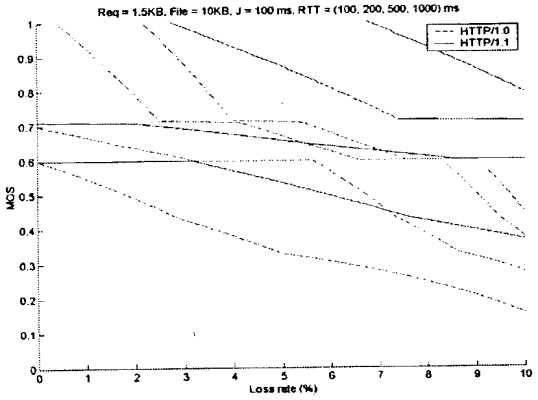

Req = 1.5KB, File = 60KB, J = 100 ms, p = (0, 1, 2, 5, 10)%
HTTP/1.0
HTTP/1.1
MOS
One-way delay (ms)

FIG. 20

(1)


Req = 1.5KB, File = 1.5KB, J = 100 ms, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
MOS
Loss rate (%)

(2)


Req = 1.5KB, File = 10KB, J = 100 ms, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
MOS
Loss rate (%)

(3)

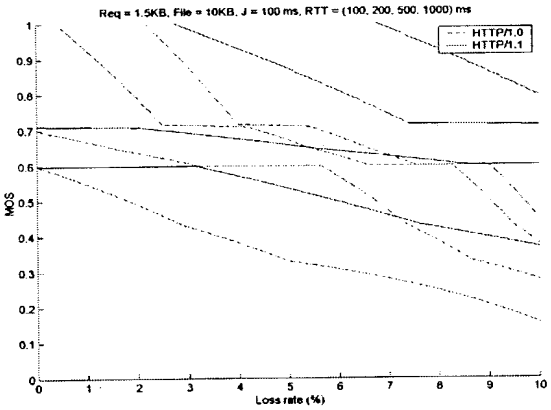
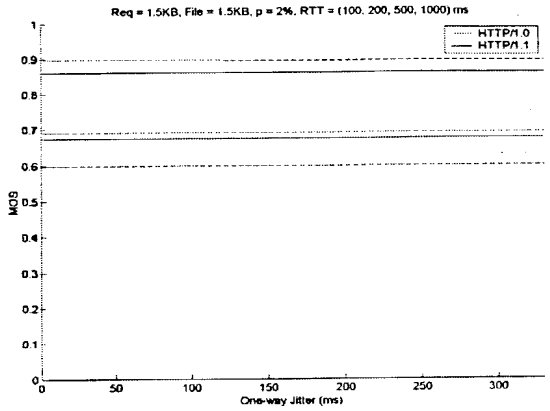
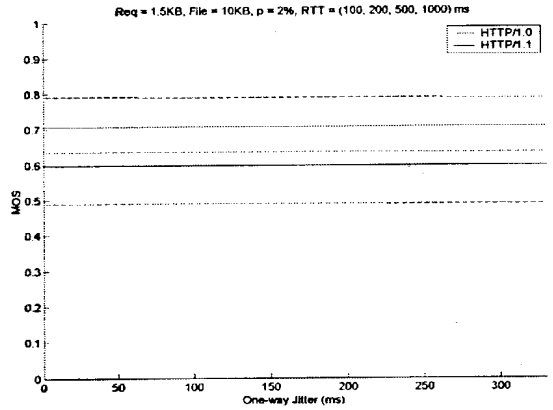

Req = 1.5KB, File = 10KB, J = 100 ms, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
MOS
Loss rate (%)

FIG. 21

(1)


Req = 1.5KB, File = 1.5KB, p = 2%, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
MOS
One-way Jitter (ms)

(2)


Req = 1.5KB, File = 10KB, p = 2%, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
MOS
One-way Jitter (ms)

(3)

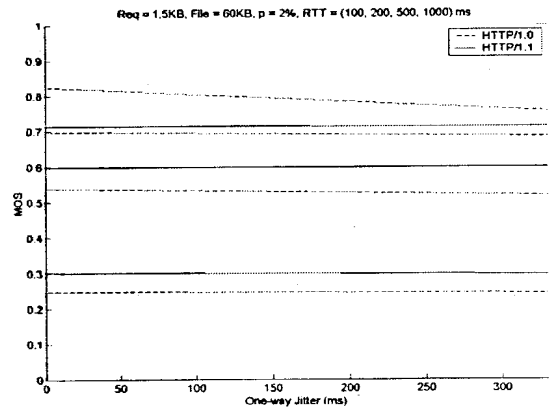

Req = 1.5KB, File = 60KB, p = 2%, RTT = (100, 200, 500, 1000) ms
HTTP/1.0
HTTP/1.1
MOS
One-way Jitter (ms)

FIG. 22

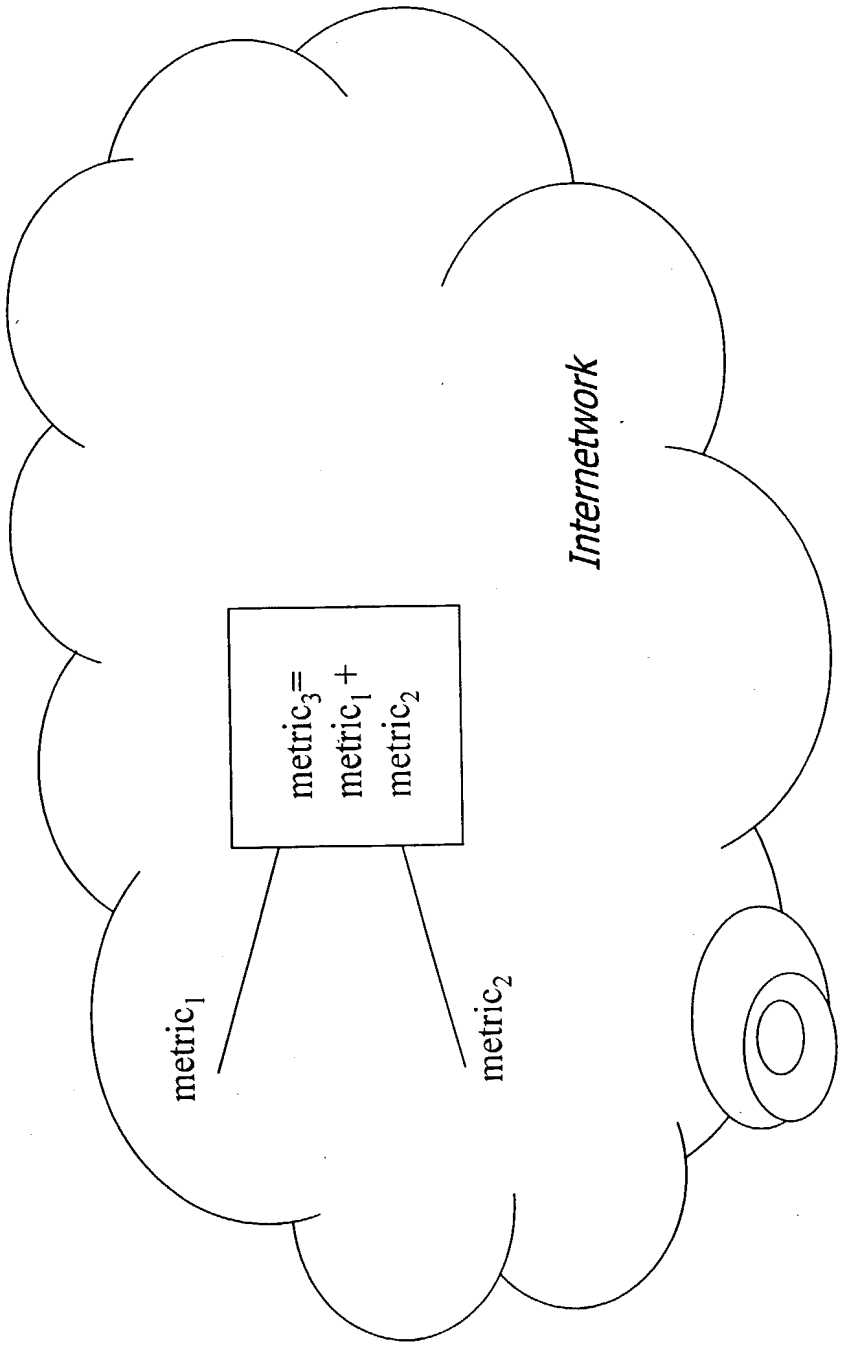


FIG. 23

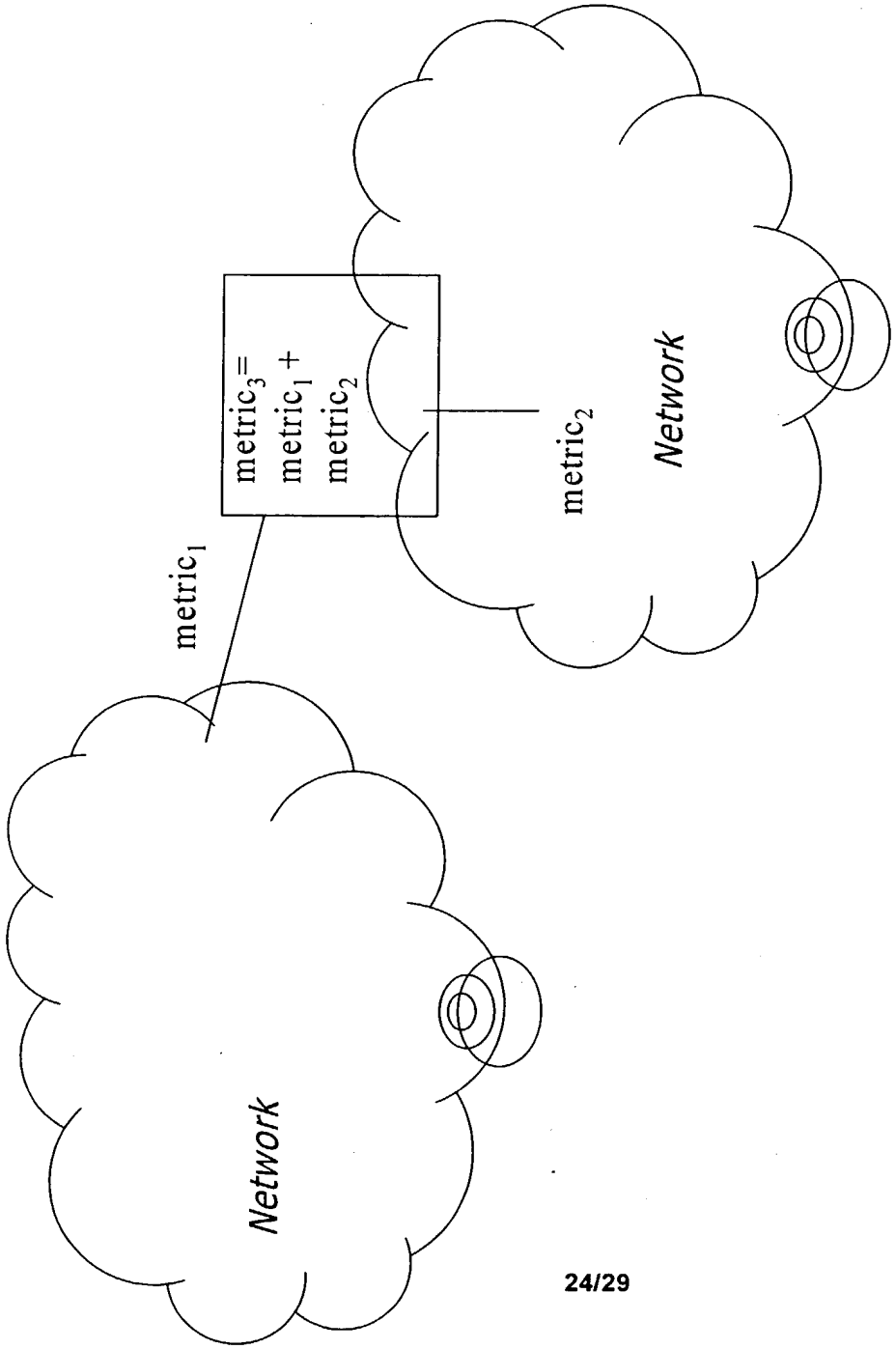


FIG. 24

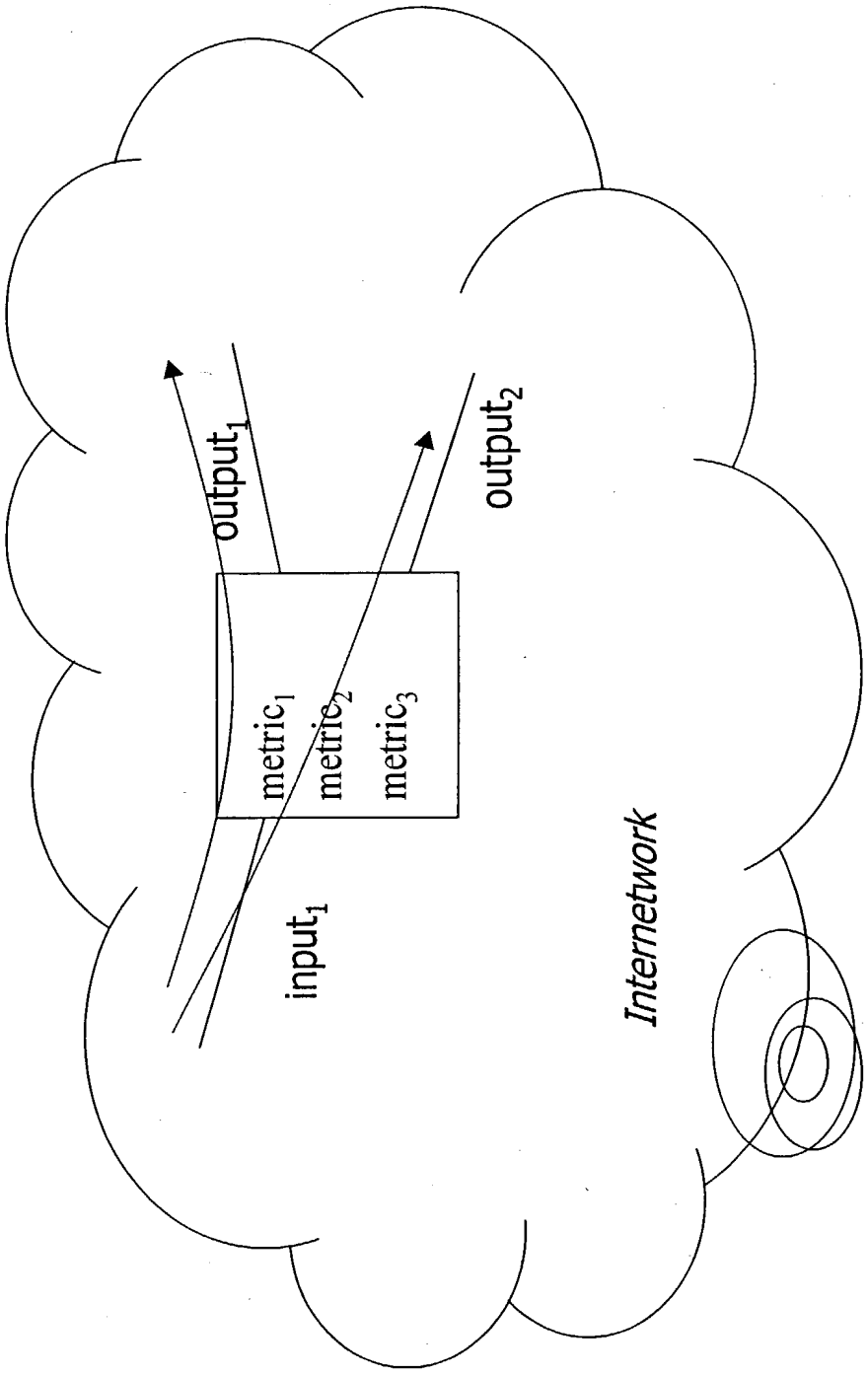

output1
output2
metric1
metric2
metric3
input1
Internetwork

FIG. 25

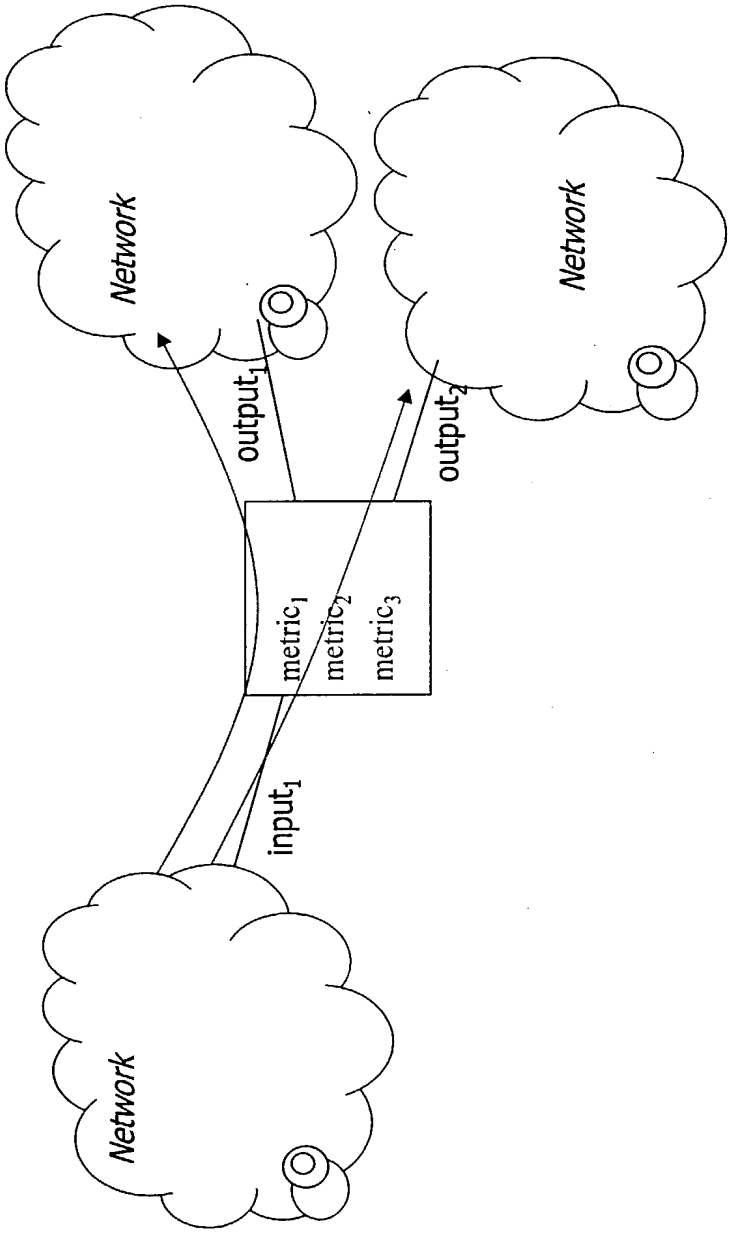
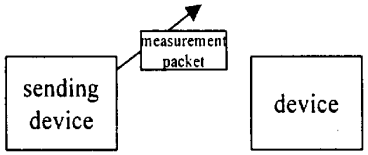
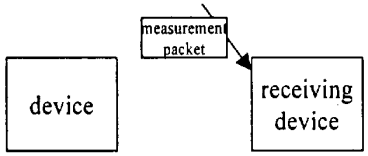

Network
Network
Network
output1
output2
input1
metric1
metric2
metric3

FIG. 26

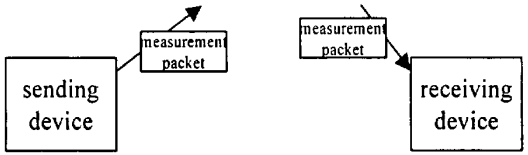
Example 1 – system with sending devices



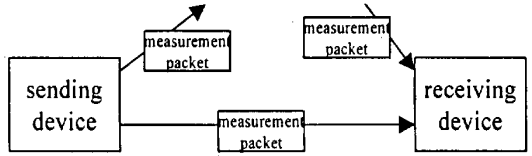
Example 2 – system with receiving devices



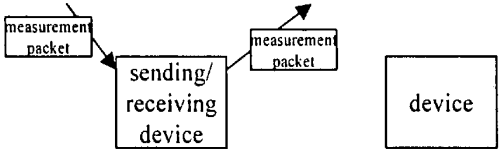
Example 3 – system with sending devices and receiving devices



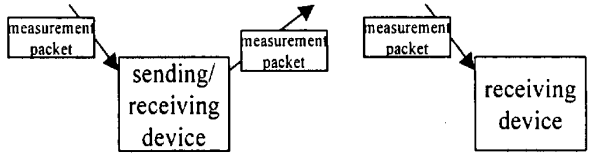
Example 4 – system with sending devices sending packets to receiving devices



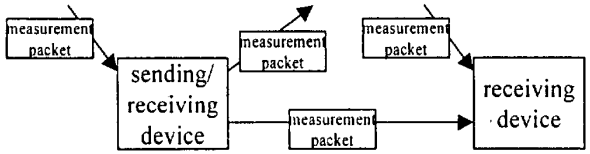
Example 5 – system with sending/receiving devices



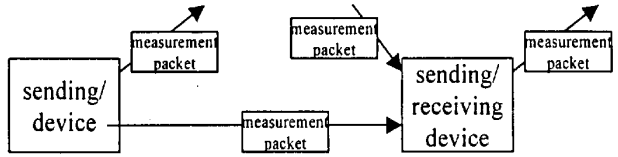
Example 6 – system with sending/receiving devices and receiving devices



Example 7 – system with sending/receiving devices sending packets to receiving devices



Example 8 – system with sending/receiving devices receiving packets from sending devices



Example 9 – system with sending/receiving devices sending packets to sending/receiving devices

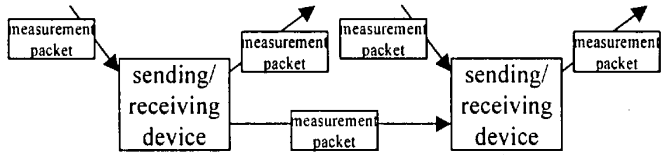


FIG. 27

10/070338

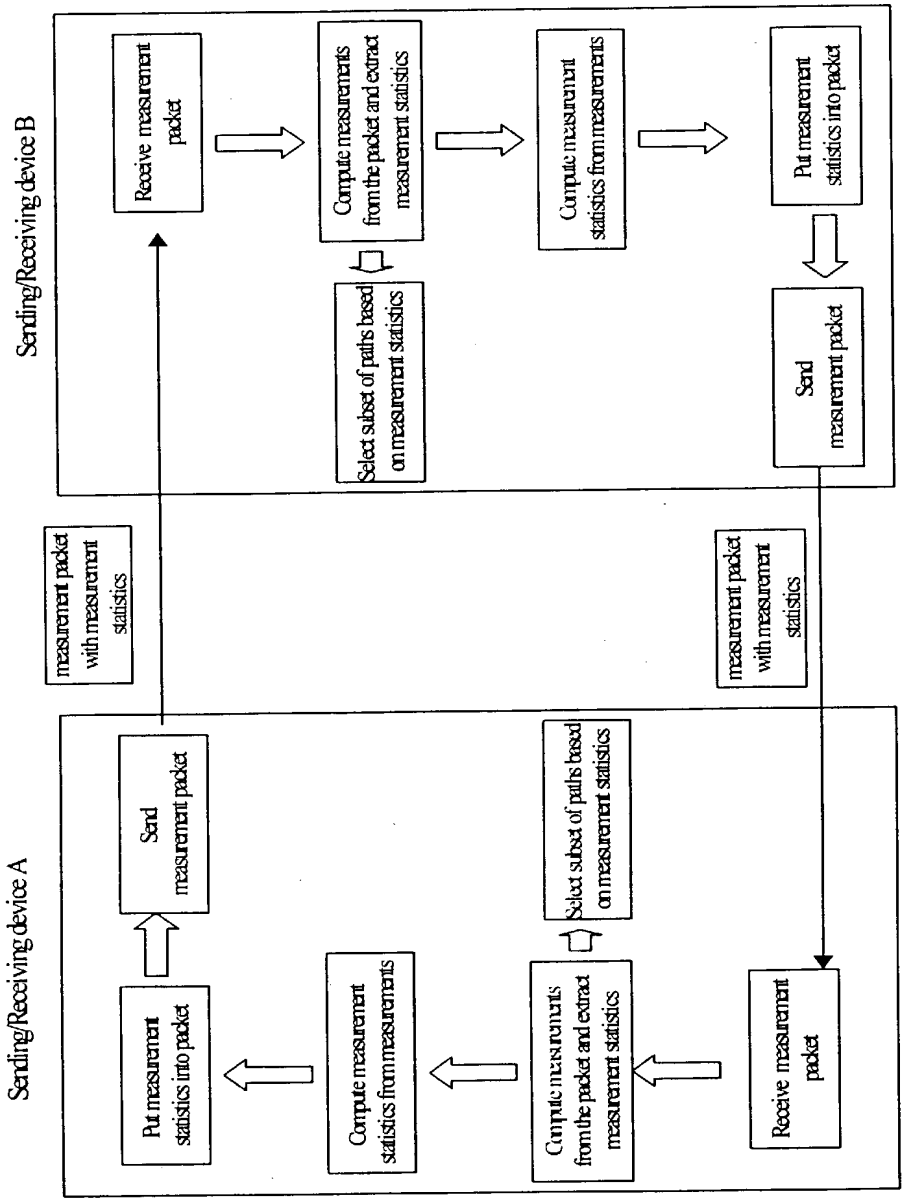

Sending/Receiving device A
Sending/Receiving device B
Receive measurement packet
Compute measurements from the packet and extract measurement statistics
Select subset of paths based on measurement statistics
Compute measurement statistics from measurements
Put measurement statistics into packet
Send measurement packet
measurement packet with measurement statistics
Receive measurement packet
Compute measurements from the packet and extract measurement statistics
Select subset of paths based on measurement statistics
Compute measurement statistics from measurements
Put measurement statistics into packet
Send measurement packet
measurement packet with measurement statistics

FIG. 28

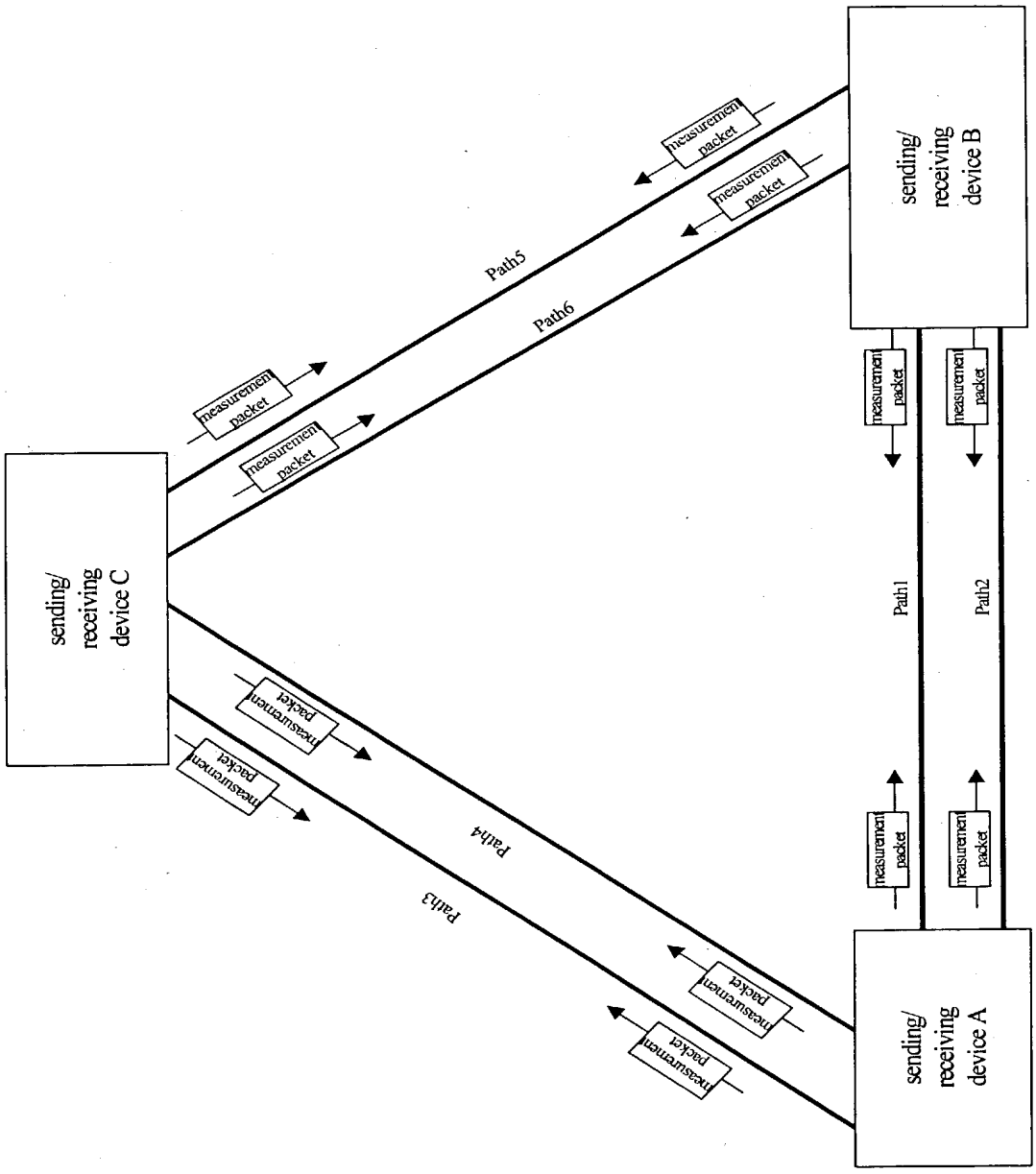

sending/
receiving
device C
sending/
receiving
device B
sending/
receiving
device A
Path1
Path2
Path3
Path4
Path5
Path6
measurement
packet

FIG. 29